afr

DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

STUDIES IN TEAR RESISTANCE OF VULCANIZED RUBBER

Project Title:	Test Methods for Rubber
Project No.:	TB4-521E
Report No.:	1
RIA Lab.No.:	52-1971
Date:	12 June 1952

*MSG DI4 DROLS PROCESSING-LAST INPUT IGNORED

*MSG DI4 DROLS PROCESSING - LAST INPUT IGNORED

```
--     1   OF     1
--                      ***DTIC DOES NOT HAVE THIS ITEM***
-- 1 -  AD NUMBER: D422602
-- 5 -  CORPORATE AUTHOR: ROCK ISLAND ARSENAL  ILL
-- 6 -  UNCLASSIFIED TITLE:     STUDIES IN TEAR RESISTANCE OF VULCANIZED
--      RUBBER.
-- 9 -  DESCRIPTIVE NOTE: REPT. NO. 1,
--10 -  PERSONAL AUTHORS: OSSEFORT,Z. T. ;
--11 -  REPORT DATE:      JUN 12, 1952
--12 -  PAGINATION:     40P
--14 -  REPORT NUMBER:    RIA-52-1971
--20 -  REPORT CLASSIFICATION:  UNCLASSIFIED
--22 -  LIMITATIONS (ALPHA):    APPROVED FOR PUBLIC RELEASE; DISTRIBUTION
--      UNLIMITED. ~~AVAILABILITY: ROCK ISLAND ARSENAL, LAB., ROCK ISLAND,~~
--      ~~ILLINOIS. 61201~~
--33 -  LIMITATION CODES:  1 [redacted]

-- END              Y  FOR NEXT ACCESSION               END
```

PC 6/6/77

NR

no ad #1

afr

(10) Z. T. Ossefort

STUDIES IN TEAR RESISTANCE OF VULCANIZED RUBBER

Project Title:	Test Methods for Rubber
Project No.:	TB4-521E
Report No.:	1
RIA Lab.No.:	52-1971
Date:	12 June 1952

ROCK ISLAND ARSENAL LABORATORY

Authorized by: O.O. 423/92 (RIA 423/2171)

Project No.: TB4-521E

Project Title: Test Methods for Rubber

Report No.: 1

RIA Lab.No.: 52-1971

Priority: 2A-2

STUDIES IN TEAR RESISTANCE OF VULCANIZED RUBBER

Object

The object of this investigation was to study the mechanism involved in the tearing of rubber and ultimately to develop a reproducible laboratory method for measuring tear resistance which would be indicative of the life of Ordnance rubber material in service.

Summary

A survey of the literature with reference to tear resistance of rubber has indicated that presently used methods of measuring the resistance of rubber vulcanizates to tearing are inadequate in that none furnish data of sufficient reproducibility. The basic mechanism involved in the tearing of rubber is extremely complex, owing to the fact that it differs with the type polymer being

tested and also because of the numerous variables associated with this type of test. Some of the requirements of a good tear test and the many variables in testing are listed herein.

In pursuit of the above objective, a program (Appendix I) was drawn up and submitted to Office, Chief of Ordnance, and the SAE-ASTM Technical Committee, Subsection IV J, on tear testing for their approval and/or comments. The program as approved was divided into four phases, as follows:

Phase I, Basic information for control purposes.

Phase II, Determination of mechanism of tear.

Phase III, Collation of results and deductions therefrom.

Phase IV, Specifications.

The work described in the present report is primarily concerned with Phases I and II of the overall program.

Results reported herein include information and data on the following factors entering into tear resistance:

1. Effect of molded ASTM (B) and Graves specimens versus die cut specimens.
2. Effect of varying the speed of elongation during testing from 5 to 240 inches per minute.
3. Influence of sample thickness on tear resistance.
4. Attempt to correlate tear resistance with conventional physical measurements.

5. Results of a compounding study, which was made to determine the effect of reinforcing filler particle size and structure on tear resistance, and also to determine the percent average deviation of tear resistance results in a series of compounds using three different polymers (Butyl, GR-S, and Hevea).
6. Percent average deviations in Scott tensile test results using vulcanizates prepared from the same three formulations as in 5. above.
7. Relationship of tear resistance and modulus using N.B.S. strain tester.
8. Results using various types of tear specimens.
9. Energy at rupture of Graves and ASTM (B) specimens at different rates of elongation.
10. Investigation of tear propagation under constant load.

Conclusions

None of the factors concerned with tear resistance which have been investigated show any degree of positive correlation with tear resistance except tensile. It is believed that presently used tear specimens merely represent more complicated tensile specimens, since some positive correlation may be found between the tensile strength using the standard dumb-bell specimens and tear results using ASTM(B) and Graves specimens. It would

appear from data thus far acquired that the lack of reproducibility in tear testing is not a great deal different from the lack of reproducibility using the standard tensile test. This is primarily caused by the non-homogeneity of the rubber vulcanizate itself when tested by a stress strain type of measurement.

Recommendation

It is recommended that Phase III and IV of the program not be completed, since no definite conclusions can be otained from Phases I and II leading to a suitable test method or specification.

It is recommended that future Ordnance research and development work center on a test method which more closely simulates service conditions such as the cut-crack-chip resistance of rubber in heavy sections.

Distribution

No. of Copies	To
1	Chief of Ordnance, ATTN: ORDTX-AR
8	Chief of Ordnance, ATTN: ORDTB - Materials
1	Chief of Ordnance, ATTN: ORDTM
1	Chief of Ordnance, ATTN: ORDTR
1	Chief of Ordnance, ATTN: ORDTS
1	Chief of Ordnance, ATTN: ORDTT
1	Chief of Ordnance, ATTN: ORDTU
2	Chief of Ordnance, ATTN: ORDIX
2	Aberdeen Proving Ground
1	Detroit Arsenal
2	Frankford Arsenal
1	Picatinny Arsenal
1	Springfield Armory
1	Watertown Arsenal
1	Watervliet Arsenal
1	Office of Naval Research, Mechanics and Materials Branch
2	Central Air Documents Office, U.B.Bldg., Dayton 2, Ohio, ATTN: CADO-D
1	Engineering Research and Development Laboratories, Fort Belvoir, Virginia
1	Materials Laboratory, Research Civ., WCRTE, Wright Air Development Center, Dayton, Ohio.
1	Ordnance Advisory Committee
15	SAE-ASTM Technical Committee, Sub-Section IV J
2	Chief of Naval Research, c/o Science & Tech. Proj., Library of Congress, Washington 25, D.C.

Contents

	Page No.
Object	2
Summary	2
Conclusions	4
Recommendation	5
Distribution	6
Introduction	8
Procedure	11
Results	15
Discussion	18
References	22
Appendix I	23

Tables I through XIV

Figures 1 and 2

Introduction

1. The two most commonly used laboratory methods of determining tear resistance in this country, namely, the Graves Angle test (ASTM D624-48 Die C) and the Crescent test (ASTM D624-48 Die A or B), do not have sufficient reproducibility, nor can they be relied upon to differentiate tear initiation and tear propagation. In addition, it is believed that presently used methods for estimating tear resistance do not reflect the true manner in which most tearing in service occurs. In a large majority of the cases of tearing in service, the tear occurs by a cutting, chipping, cracking or gouging method, rather than by the modified tensile type tear test as used in the laboratory. The latter test would apply mainly in the case of comparatively thin flat rubber articles, such as inner tubes, gaskets, boots, bellows, etc., whereas, the former type tearing would occur in much more prevalent Ordnance items, such as tires, bogie wheels, track blocks, etc. A great many other tear tests have been proposed[1] but none seem to possess good reproducibility or to correlate with the actual tearing of rubber articles in service. There is a great need for a tear test which will have the following characteristics:

A. Reproducibility ± 5 percent average deviation.

B. Differentiate between tear initiation and tear propagation.

C. Ease of manipulation - mechanical simplicity.

D. Applicable to all types of polymers.

E. Suitable for use in all states of cure of rubber and using various compounding ingredients.

F. Simulate the manner in which most tearing takes place in service.

That a better tear test is required is also indicated by the fact that Morris and Gerwels[2] found in a study of 21 different laboratories that values of tear strength differed by 79% as compared with differences of 28% in hardness, 15% elongation at break, 48% in tensile and 75% in modulus.

2. The mechanism involved in the tearing of rubber is extremely complex and difficult of analysis. It is made more involved by the fact that the mechanism may differ, depending upon whether the polymer used is a crystallizable or non-crystallizable type. Thus, butyl rubber frequently exhibits the phenomenon referred to as "knotty tear". Buist[3] states that this same effect may be observed in other polymers and he even found a case of knotty tear with a natural rubber gum stock. There appears to be much controversy in the literature with

reference to the question of tear initiation and tear propagation. Thus Buist[4] claims that the angle tear method (ASTM D624-48 Die C) gives a measure of tear initiation, whereas, the Crescent (ASTM D624-48 Die A or B) tear is a tear propagation method. On the other hand, Nijveld[5] cannot support this view. The latter author believes that in both tests a tear is initiated, with a tear being a propagation of an incision in the one and excision in the other.

3. Additional factors which complicate the study of tear testing are the numerous variables which are involved. Probably the most important of these are the following:

A. Mechanical fibering of the rubber under stress.

B. Stress distribution in the specimen - Shape of sample.

C. Speed of stretching.

D. Size and thickness of specimen and depth of nick.

E. Number of nicks and depth of nick in nicked type specimens.

F. State of cure.

G. Direction of grain.

H. Modulus.

I. Effect of reinforcing fillers - particle sizes.

J. Temperature of testing.

K. Length and degree of milling time.

L. Hardness of rubber compound.

M. Plasticizer type and amount.

N. Effect of crystallizability of polymer.

O. Effect of edge smoothness of specimens - die cut versus molded.

P. Radius of curvature of specimens.

Procedure

4. With the object of studying the mechanism of tearing in rubber articles, a program was drawn up and submitted to the SAE-ASTM Sub-committee IV J for their comments and recommendations (See Appendix I). Briefly, this program as approved was divided into four broad phases, consisting of the following:

Phase I, Basic information for control purposes

Phase II, Determination of mechanism of tear

Phase III, Collation of results and deductions therefrom

Phase IV, Specification.

Most of the work included herein was under Phases I and II. Since there are so many variables associated with tear testing, it was decided to attempt to establish a backlog of basic information relative to tear testing and thus be able to eliminate at least a few of the variables. Therefore, three polymers were chosen based on the greatest usage and consisting of one non-crystallizable type (GR-S), one crystallizable type (Butyl), and natural rubber as a

control, since such a great volume of work in the literature is reported relative to natural rubber. For the non-crystallizable type, GR-S 50 was selected, while butyl represented the crystallizable polymer. According to Buist[6], butyl rubber is a very convenient polymer to use in the study of the mechanism of tearing, since it has a high permanent set which is sensitive enough to show up some of the stress gradients in the sample.

5. A mold was prepared for curing the ASTM(B) and Graves tear specimens, and a comparison was made between specimens which had been molded and those which were die cut from a flat sheet. The Dinsmore, Wright, Patrikeev Melnikov and Goodyear "tongue tear" specimens were also evaluated.

6. It has been reported[7] that a higher load for tearing is observed with increased speed. Thus a change of speed of tearing across the specimen from 300 to 1000 inches per minute is said to produce a 30% increase in load. Equipment was not available in this laboratory for measuring this speed of tearing, but using the Thwing - Albert Electro Hydraulic Tensile Tester (Fig. 1), changes in the rate of elongation were examined. Tests were performed using jaw separation speeds of 5, 20, 30 and 240 inches per minute. The latter speed represents the maximum this machine is capable of developing.

7. Two molds were made which would give rubber sheets of approximately 260 and 130 thousandths of an inch thickness. Tear specimens were die cut from these pads and from the standard tensile pads which are .080 inch thick, and a comparison of the effect of varying sample thickness was made. The number and angles of the nicks were varied on the ASTM (B) specimen. Angles of 30°, 45° and 60°, parallel and converging, were investigated.

8. The energy at failure for natural rubber, GR-S and butyl, using both ASTM (B) and Graves specimens, was calculated at various rates of elongation by measuring the area under the stress-strain curve.

9. Tear propagation by nicking a specimen 1" x 6" x .085" when held under a specified load was also investigated. The load was changed at the start of each test and the length the tear progressed was measured for this load. This procedure was continued at successively heavier loads until the specimen failed.

10. Since it appeared from information obtained in this investigation and previous work on this subject, that a definite correlation could be found between tear resistance and elongation, three tear tests and seven commercial polymers were investigated in an attempt to elucidate or define this correlation, if such could be found.

11. A compounding survey was conducted with the object of determining the effect of reinforcing filler

particle size and structure on the tear resistance. Three typical gum rubber stocks, whose formulae are furnished in Table I, were chosen for this study and consisted of natural rubber, GR-S, and butyl. Six fillers varying in particle size and structure (Table II) were incorporated into each of the base polymers. The physical properties (Table III) of tensile, elongation, modulus, Shore A hardness, Lupke resilience and compression set were determined on the resulting twenty-one compounds. A survey was made of the Graves and ASTM(B) tear tests, using ten test specimens of each of the above described compounds. After this data was analyzed, it was found desirable, for purposes of comparison, to perform the same type of survey on the standard tensile test. The same rubber stocks and number of specimens were used in this investigation and the data analyzed in the same fashion.

12. In an effort to correlate tear resistance with some fundamental property of rubber other than tensile strength, the natural rubber, GR-S, and butyl rubber compounds prepared for the compounding survey were tested, using the N.B.S. strain tester (Fig. 2) which determines the elongation produced by a given load. In connection with this same objective, various attempts were made to correlate tear resistance measurements with the radius of curvature of the test specimen.

Results

13. Data for the specimens, which had been molded as compared with those which had been die cut from standard test pads, is presented in Table V. Tests were conducted at speeds of 5, 20, 30, and 240 inches per minute. These results indicate that there is no direct correlation between tear results determined at the various speeds nor between molded and die cut specimens.

14. The data furnished in Table VI indicates that it is not possible to achieve greater reproducibility in the tear values, using the Graves and ASTM(B) tear tests, by increasing the specimen thickness. It is also shown that there is considerable but irregular variation in the value of tear expressed in pounds per inch of thickness, depending upon the thickness of the specimen taken.

15. The "tongue" specimens gave results that were considerably lower than either ASTM (B) or Graves (Table IX). This type of specimen is more susceptible to knotty tear, and therefore gave percent average deviations greater than the ASTM (B) or the Graves specimens.

16. The angle at which the nick is initiated on the ASTM (B) specimen has little effect on the tear resistance in pounds per inch of thickness (Table VII).

As the number of nicks are increased, the tear resistance increases, indicating a more equal distribution of forces.

17. Table VIII indicates that it requires a greater load to produce failure in the GR-S than in either the butyl or Hevea stocks when the load is held constant during each test.

18. The $\frac{\text{in-lb.}}{\text{sec.}}$ of energy at failure is directly dependent upon the speed of the tester and does not seem to be related to any other physical property (Table X).

19. To study the correlation between tear resistance using the standard tear tests and elongation, tear resistance measurements were made using three standard methods on seven commercial polymers. Results (Table XI) indicate that there is some correlation between tear resistance expressed as pounds pull per inch of thickness and the percent elongation at break. The Graves test does not appear to be specific enough in values that enable adequate differentiation between various polymer stocks. Further work correlating tear and elongation might prove to be profitable.

20. The data obtained from the compounding survey previously described is presented in Tables III, XII and XIII. It will be seen that a regular increase or decrease in the value of each property measured follows the increase

in particle size of the filler, thus demonstrating the effect particle size of filler exerts on vulcanizates. Results of the data furnished in Table XII indicate that accuracy and reproducibility cannot be made a basis of choice between Graves and ASTM methods, since they both show approximately equal overall percentage average deviations. On the basis of convenience of test procedure, one would choose the Graves test method because no nick is required. The relative validity of the two methods is seen to depend to a certain extent on the type of polymer chosen for test. For example, with natural rubber, the ASTM method shows a slightly lower percentage average deviation, while with both the GR-S and butyl the reverse is true. For both types of tear tests using the various fillers in the three polymers, the overall average deviation is about 11%. Similar results for comparable studies are shown in reference 5.

21. Results of the tensile test survey (Table XIII), using the same rubber stocks as were used in the tear series above, indicate that the reproducibility of the tear tests at 11% average deviation approximates that of the tensile test at 7.5% average deviation.

22. From the data shown in Table IV, it may be seen that there is no positive correlation between tear resistance and modulus as measured by the N.B.S. strain tester.

Further efforts to correlate tear resistance with the radius of curvature in the test specimens also proved to be fruitless.

Discussion

23. In the computations of the average deviations, the following method of rejecting doubtful measurements was utilized. Omitting the doubtful measurement, the mean of the series was computed and the average deviation of a single measurement from the mean determined. Next, the deviation of the doubtful measurement from the mean was computed. If its deviation was greater than five times the average deviation, it was rejected. This simple rule is based on the fact that granting the normal distribution law, the frequency of occurrence of an observation having a deviation from the mean greater than five times average deviation is less than one in a thousand. The percent average deviation obtained from the resulting groups of values represent pure numbers and have no relationship to the relative pound values of the tear resistance as obtained in either the ASTM(B) or Graves methods.

24. Of all the factors thus far studied in this investigation, only tensile strength bears any positive correlation with tear resistance (Table XIV). It appears also that in all tear tests thus far proposed

and described in the literature, the tear is a composite effect resulting from both a tensile and shear component of the applied stress. It would seem that the fundamental problem involved is separation of the former from the latter. The data presented herein have shown that the percent average deviations in both the tear and tensile tests are of the same order of magnitude. This demonstrates that the presently used tear tests are merely examples of a more complicated tensile test. It would seem, therefore, that there are only two courses of action which remain to be investigated. That is, one may begin with the object of improving the mechanics and reproducibility of the more basic and longer used tensile test, or one may seek some entirely new approach to a tear process which is completely divorced from the tensile, if such a test can be conceived. However, the real difficulty may be even more basic than mentioned heretofore. That is to say, one may be confronted with the enigma of attempting to obtain uniform results from a material which is in itself essentially non-homogeneous. As is well known, a laboratory technician may take a standard test pad and find that dumb-bell specimens die cut within the same 6" x 6" test pad (or even molded separately) and in the same grain direction will yield a percentage average deviation of approximately 10% when

tested on the standard Scott tensile tester. Such results can be duplicated as frequently and regularly as desired, regardless of numerical value of tensile, type of filler, content of plasticizer, etc. Increasing the complexity of the dumb-bell test specimen to arrive at such specimens as the angle tear test and Crescent tear test, only serves to complicate the determination of the original tensile strength, since it has been found that a direct relationship exists between the two in each case.

25. The further investigation of tearing of rubber, it is believed, should be more valuable if the emphasis were shifted from a study of the tensile type tests and placed upon the development of a test which would more nearly reflect the condition of tearing in the majority of cases in service. As previously mentioned, this is taken to be a device which will in some manner simulate the cutting, cracking, chipping or sharp penetrations observed in failures of tires, bogie wheels, tank track blocks, etc. Of course, the same conclusions regarding non-homogeniety of the rubber will also apply in this case and one could hardly expect much greater than 10% reproducibility, but here the test would at least be more representative of conditions most frequently encountered in service.

Report by: Z. T. Ossefort

Tests by: W. J. Touhey
A. C. Saunders

Supervised by: R. F. Shaw

Approved by: A. C. HANSON

References

(1) Reinsmith G., India Rubber World, 116, 449 (July 1947)

(2) Morris, H. B., and Gerwels, C.H.,Rubber Age,61,323(1947)

(3) Buist, J.M. Trans. Inst. Rubber Ind., 20, 155 (1945)

(4) Buist, J.M. Reprint - Rubber Technology Conference, London, June 23-25 (1948), P. 269

(5) Nijveld, H.A.W., Reprint - Rubber Technology Conference, London, June 23-25 (1948) P.267

(6) Buist, J.M., Reprint - Rubber Technology Conference, London, June 23-25 (1948) P. 276

(7) Trans. Inst. Rubber Ind., 10, 80 (1934)

APPENDIX I

Tear Resistance of Rubber
Project TB4-521E, Problem 1

Phase I, Basic Information for Control Purposes

A. Polymers (based on Greatest usage)

1. GR-S (Non-crystallizable)

2. GR-I (Crystallizable)

3. Natural Rubber

B. Test Specimens (Standard) and thicker

1. ASTM Specimen b

a. Un-nicked)
(cut and molded
b. Nicked)

2. Graves (Molded) and cut

C. Speed (Electro-Hydraulic Tensile Tester)

1. 5"/minute

2. 20"/ minute

3. 30"/minute

4. 240"/minute

D. Compounding Study

1. Gum Rubber Stock

2. Carbon (particle size effect)

a. Channel (HPC or finer)

b. Furnace HAF

c. Furnace SRF

d. Acetylene

e. Thermax

3. Cure

   a. For highest tear resistance

   b. For highest tensile strength

   c. Overcure

4. Softeners (Saturated Petroleum, esters and polymeric)

   a. No plasticizer

   b. Low percent plasticizer (5%)

   c. High percent plasticizer (10%)

5. Determine effect of Banbury mixing and mill rolling procedures.

E. Properties to be measured

1. Tensile strength

2. Elongation

3. Modulus

4. Durometer

5. Resilience

6. Abrasion

7. Tear resistance

   a. Initiation

   b. Propagation

F. Select one representative compound for each polymer for further tests.

Phase II, Determination of Mechanism of Tear

A. Effect of variables in test methods and conditions, using test specimens and compounds selected in Phase I.

1. Specimen size

   a. Vary thickness

   b. Vary width

2. Nicks

   a. Vary depth

   b. Vary number

   c. Vary angle

   d. Cut specimen so nick will be perdendicular to grain

   e. Cut specimen so nick will be parallel to grain

3. Determine force for initiation and propagation of tear

4. Determine energy for initiation and propagation of tear

5. Determine effect of temperature on tear resistance

6. Determine effect of very high speeds (0.5 to 1000 inches/second)

   a. Note load variations with speed

   b. Study high speed pictures of tearing

B. Effect of varying types of specimens

1. Specimens

   a. Dinsmore Specimen

      (1) Maintain thickness, speed, temperature and compounding constant

      (2) Determine force and energy for propagation of tear, both perpendicular and parallel to grain

b. Wright Specimen

(1) Same as II.B.1.a.(1)

(2) Same as II.B.1.a.(2)

c. Patrikeev & Melnikov Specimen

(1) Same as II.B.1.a.(1)

(2) Same as II.B.1.a.(2)

d. Elmendorf Method

e. Rectangular Specimen

(1) Apply a given load

(2) Nick specimen 1/8"

(3) Determine load required to cause complete failure when tear is initiated by a nick (vary applied load until complete failure occurs when nick is initiated)

(4) Photograph tear propagation with high speed camera

2. Method of Test

a. Constant rate of jaw separation

b. Constant rate of elongation

Phase III, Collation of Results and Deductions therefrom

A. Correlate tear resistance with physical properties

B. Correlate tear resistance with service tests

C. Deduce theory of mechanism of tear

D. Select best method to give desired results and reproducibility

Phase IV, Specifications

A. Determine specification limits

B. Write specification

List of Tables and Figures

Table I - Formulae of Rubber Stocks

Table II - Particle Size and Degree of Structure of Fillers used in Compounding Survey

Table III - Physical Properties of Rubber Stocks used in Compounding Survey

Table IV - Comparison of Tear Resistance with Strain Tests

Table V - Tear Resistance Measurements of Molded Graves and ASTM (B) Specimens versus Die Cut Specimens

Table VI - Effect of Variation of Sample Thickness on the Reproducibility of Tear Results using the Graves and ASTM (B) Methods

Table VII - Effect of Angle and Number of Nicks in the ASTM (B) Specimen

Table VIII - Tear Propagation

Table IX - Tear Resistance Measurements of Tongue Tear Specimens

Table X - Energy at Break of ASTM (B) and Graves Specimens

Table XI - Investigation of Relationship between Tear Resistance and Elongation at Break

Table XII - Percentage Average Deviations in Tear Results of Hevea, GR-S and Butyl filled with Various Particle Sized Fillers

Table XIII - Percentage Average Deviations in Tensile Results

Table XIV - Comparison of both ASTM (B) and Graves Tear Resistance Values with Tensile Strength in Natural Rubber, GR-S and Butyl

Fig. 1 - Thwing, Albert, Electro Hydraulic Tensile Tester used for Measuring Tear Resistance at Varying Rates of Jaw Separation.

Fig. 2 - N.B.S. Strain Tester

TABLE I

FORMULAE OF RUBBER STOCKS

	RIA #A8	RIA #T7	RIA#S7F1
Natural Rubber - Pale Crepe	100	-	-
Butyl - GRI	-	100	-
GR-S - Standard	-	-	100
Zinc Oxide	5	5	5
Stearic Acid	1	3	1
Agerite Hipar	1	-	-
Neozone D	-	-	1
Methyl Tuads	3	1	-
Santocure	-	-	1
Sulfur	0.5	1.5	1.75
Plastogen	1	-	-
TP 90B	-	-	10
	111.5	100.5	129.75

The following six fillers were incorporated into each of the above gum stocks in the amounts shown below:

Conductive Channel	50	20	50
Hi Sil	54	22	54
High Abrasion Furnace	50	20	50
Acetylene Black	50	20	50
Semi Reinforcing Furnace	50	20	50
Thermax	50	20	50

TABLE II

PARTICLE SIZE AND DEGREE OF STRUCTURE OF FILLERS USED IN COMPOUNDING SURVEY

Filler	Symbol	Diam. Millimicrons	Type Agglomeration
Conductive Channel	CC	10-20	Normal
Hi Sil	--	25	--
High Abrasion Furnace	HAF	36	High
Acetylene Black	ACET	43	Very High
Semi-Reinforcing Furnace	SRF	70-90	Normal
Thermax	MT	250-500	Low

TABLE III

PHYSICAL PROPERTIES OF RUBBER STOCKS USED IN COMPOUNDING SURVEY

50 PARTS FILLER - INCREASED PARTICLE SIZE ⟶

	CC	HISIL	HAF	ACET	SRF	MT	GUM
Natural Rubber A8							
Tensile	4060	3170	2880	2540	2300	2500	2540
300% Modulus	1870	1220	-	-	-	850	125
% Elongation	500	600	300	350	340	460	650
Hardness	77	67	72	68	61	50	38
Tear ASTM (B)	960	440	530	285	300	120	110
Graves	600	575	218	210	190	145	90
Lupke Rebound	46	62	63	64	72	74	77
Comp. set (B), 22 hrs. at 158°F.	15	19	8	8	6	6	5
GF-S S7F1							
Tensile	2410	890	2500	1950	1770	640	160
300% Modulus	1630	184	1500	1500	915	300	140
% Elongation	600	820	400	370	490	430	400
Hardness	66	54	58	64	53	47	40
Tear ASTM (B)	470	210	270	182	146	39	23
Graves	400	170	182	175	150	87	21
Lupke Rebound	38	46	52	51	56	60	62
Comp. set (B) 22 hrs. at 158°F.	42	75	26	22	26	26	22
Butyl I7							
Tensile	2620	2500	2630	2360	2300	2275	2390
300% Modulus							
% Elongation	880	900	750	710	730	750	800
Hardness	51	39	47	51	48	42	35
Tear ASTMB	200	120	110	90	72	31	32
Graves	120	88	130	128	91	87	71
Lupke Rebound	17	18	17	17	17	20	19
Comp. set (B) 22 hrs. at 158°F.	27	17	19	19	24	35	18

Stress-strain data in this table were obtained using the Scott Tensile Tester and standard procedure.

TABLE IV

COMPARISON OF TEAR RESISTANCE WITH STRAIN TESTS

Polymer	Tear		N.B.S. Strain		
	ASTM (B)	Graves	100 psi.	200 psi.	400 psi.
Hevea - CC	904	486	11	48	122
Hevea - Hi Sil	506	232	9	68	179
Hevea - HAF	583	161	16	44	92
Hevea - Acet.	418	170	19	54	104
Hevea - SRF	397	147	27	67	137
Hevea - MT	196	133	50	137	233
Hevea - Gum	218	81	97	258	432
GR-S - CC	358	170	40	144	280
GR-S - Hi Sil	262	134	147	298	528
GR-S - HAF	283	161	46	117	185
GR-S - Acet.	219	162	34	88	150
GR-S - SRF	182	152	61	142	242
GR-S - MT	84	70	93	213	364
GR-S - Gum	43	11	115	-	-
Butyl - CC	265	102	155	346	527
Butyl - Hi Sil	190	76	235	452	623
Butyl - HAF	150	108	78	191	350
Butyl - Acet.	148	93	84	205	371
Butyl - SRF	104	83	97	240	369
Butyl - MT	55	56	134	317	506
Butyl - Gum	48	60	186	375	-

TABLE V

TEAR RESISTANCE MEASUREMENTS OF GRAVES AND ASTM (B) MOLDED SPECIMENS VERSUS DIE CUT SPECIMENS

Speed	RIA Compound	Graves Die Cut Av. Tear	Ave. Dev.	% Ave. Dev.	% Elong.	Graves Molded Ave. Tear	Ave. Dev.	% Ave. Dev.	% Elong.
5"/min.	S7	170	7	4	100	166	17	10	106
20"/min.	S7	176	17	10	114	163	24	15	114
30"/min.	S7	195	15	8	105	180	22	12	100
5"/min.	I7	110	4	4	400	106	11	10	190
20"/min.	I7	115	2.4	2	420	120	9	8	187
30"/min.	I7	118	4.4	4	375	135	11	8	205
		ASTM(B) Die Cut Ave. Tear				ASTM(B) Molded Ave. Tear			
5"/min.	S7	203	17	8	158	184	33	18	173
20"/min.	S7	187	20	11	150	181	15	8	139
30"/min.	S7	163	16	10	115	220	21	10	153
5"/min.	I7	221	47	21	550	147	25	17	335
20"/min.	I7	180	65	36	500	141	6	4	335
30"/min.	I7	170	45	26	445	185	31	17	360
		Graves Die Cut				ASTM Die Cut			
240"/min.	A8EPC	230	38	17	-				
240"/min.	A8EPC					495	54	10	
						Un-nicked			
240"/min	A8EPC					649	88	14	

All values shown represent averages of ten tear specimens.

TABLE VI

EFFECT OF VARIATION OF SAMPLE THICKNESS ON THE REPRODUCIBILITY OF TEAR RESULTS USING THE GRAVES AND ASTM (B) METHODS

RIA # - Polymer	Thickness	Speed	Tear	Ave.Dev.	% Ave.Dev.	% Elong. at Break
			GRAVES - DIE CUT			
A8 - Hevea	.267	5"/min.	397	-	-	-
A8 - Hevea	.267	30"/min.	360	42	12	-
A8 - Hevea	.129	5"/min.	350	42	12	94
A8 - Hevea	.130	30"/min.	335	31	9	100
A8 - Hevea	.090	20"/min.	265	Scott tensile tester, using standard procedure.		
A8 - Hevea	.093	20"/min.	290	30	10	190
S7F1-GR-S	.244	30"/min.	234	-	-	-
S7F1-GR-S	.129	5"/min.	163	14	9	113
S7F1-GR-S	.129	30"/min.	163	11	7	94
S7F1-GR-S	.092	20"/min.	180	Scott tensile tester, using standard procedure.		
S7F1-GR-S	.093	20"/min.	186			230
			ASTM (B) - DIE CUT			
A8-Hevea	.269	20"/min.	405	81	20	150
A8-Hevea	.127	20"/min.	400	164	40	152
A8-Hevea	.093	20"/min.	600	Scott Tester		
S7F1-GR-S	.245	20"/min.	315	17	6	245
S7F1-GR-S	.127	20"/min.	315	26	12	189
S7F1-GR-S	.093	20"/min.	291	Scott Tester		

TABLE VII

EFFECT OF ANGLE AND NUMBER OF NICKS IN THE ASTM (B) SPECIMEN

Com-Pound	No. Nicks	Angle of Nicks	Tear Resistance Ave. lb./in.	Ave. Dev. Lbs.	% Ave. Dev.
A8	1	30°	479	31	6.5
A8	1	45°	465	22	4.8
A8	1	60°	508	20	4.0
S7F1	1	30°	207	11	5.4
S7F1	1	45°	199	10	5.0
S7F1	1	60°	209	10	4.8
I7	1	30°	90	2	2.2
I7	1	45°	108	5	4.6
I7	1	60°	114	11	9.7
A8*	2	30°	459	25	5.5
A8*	2	45°	472	25	5.3
A8*	2	60°	473	78	16.5
S7F1*	2	30°	237	-	-
S7F1*	2	45°	225	27	12
S7F1*	2	60°	254	30	11.8
I7*	2	30°	98	7	7.2
I7*	2	45°	84	3	3.6
I7*	2	60°	118	7	5.9
A8**	2	30°	431	55	12.8
A8**	2	45°	455	55	12.1
A8**	2	60°	462	60	13.0
S7F1**	2	30°	209	20	9.6
S7F1**	2	45°	209	3	1.5
S7F1**	2	60°	189	-	-
I7**	2	30°	85	12	14.2
I7**	2	45°	93	5	5.4
I7**	2	60°	84	5	6.0

* Angles measured from opposite sides of the perpendicular.

** Angles parallel. All nicks 0.02" deep, speed 20"/min.

NOTE: All compounds shown were mixed using HAF carbon black.

TABLE VIII

TEAR PROPAGATION

Compound	Thickness	Load	Lb./in.	Length of Tear
A8-HAF	.090	20	222	.156
A8-HAF	.093	30	323	.156
A8-HAF	.089	32.5	366	Failure
S7F1-HAF	.088	30	341	.187
S7F1-HAF	.090	40	445	.187
S7F1-HAF	.090	45	500	.282
S7F1-HAF	.087	47.5	546	Failure
I7-HAF	.086	10	116	.187
I7-HAF	.089	11	124	.250
I7-HAF	.089	12.5	141	Failure

TABLE IX

TEAR RESISTANCE MEASUREMENTS OF TONGUE TEAR SPECIMENS

	Compound		
	A8-HAF	S7F1-HAF	I7-HAF
DINSMORE			
Ave. Lb./in.	96	85	12
Ave. Dev. lb./in.	10	24	2
% Ave. Deviation	10	28	18
WRIGHT			
Ave. lb./in.	455	321	130
Ave. Dev. lb./in.	62	13	11
% Ave. Deviation	14	4	9
PATRIKEEV & MELNIKOV A = 60°			
Ave. lb./in.	117	108	55
Ave. Dev. lb./in.	29	16	21
% Ave. Deviation	25	14	38
GOODYEAR			
Ave. Lb./in.	15	26	-
Ave. Dev. lb./in.	5	2	-
% Ave. Deviation	33	9	-

TABLE X

ENERGY AT BREAK OF ASTM (B) AND GRAVES SPECIMENS

	0.6" min.			1.5"/min.			3.0"/min.			8.0"/min.		
	% Elong.	Lb./ in.	in-lb. Sec.	% Elong.	Lb./ in.	in-lb. Sec.	% Elong.	Lb./ in.	in-lb. Sec.	% Elong.	Lb./ in.	in-lb. Sec.
ASTM (B)												
A8-HAF	730	715	.319	647	617	.791	718	759	1.25	668	632	2.95
S7F1-HAF	538	245	.090	533	255	.258	592	299	.535	545	317	1.37
I7-HAF	715	118	.049	973	176	.348	853	140	.278	725	122	.607
GRAVES												
A8-HAF	415	279	.091	502	361	.367	385	314	.608	413	342	2.33
S7F1-HAF	502	176	.071	505	195	.174	288	189	.353	312	212	.92
I7-HAF	783	116	.043	903	130	.106	763	121	.181	833	138	.558

	20"/min.			30"/min.			40"/min.		
	% Elong.	Lb./ in.	in-lb. Sec.	% Elong.	Lb./ in.	in-lb. Sec.	% Elong.	Lb./ in.	in-lb. Sec.
ASTM (B)									
A8-HAF	660	605	7.24	650	649	11.0	612	589	13.6
S7FI-HAF	513	266	3.4	542	250	5.31	653	364	7.51
I7-HAF	855	159	1.78	1190	228	3.59	900	163	2.93
A8-HAF	402	280	3.41	335	247	3.39	323	261	5.62
S7F1-HAF	520	227	2.35	582	244	4.67	582	245	5.29
I7-HAF	1005	162	1.93	780	139	2.58	777	106	3.37

TABLE XI
INVESTIGATION OF RELATIONSHIP BETWEEN TEAR
RESISTANCE AND ELONGATION AT BREAK

Width	psi.	A1 Natural Rubber	S1-GR-S	N-3 Paracril 18	GN M-2 Neoprene	OR-15 H-5 Hycar
.250	Tensile - % Elong.	2675-650	1650-690	850-1120	1695-700	1350-980
.400	Unnicked Crescent % Elong.	710-500	550-500	310-800	640-550	425-760
.380	Nicked Crescent % Elong.	625-300	300-250	275-430	230-275	255-500
.500	Graves - % Elong.	370-135	360-150	240-300	180-140	168-425
Based on Equivalent Thickness and Width						
.500	Tensile - % Elong.	1475-575	1060-630	425-1120	850-700	675-980
.500	Unnicked Crescent % Elong.	890-500	685-500	388-800	800-550	532-760
.500	Nicked Crescent % Elong.	822-300	657-250	362-430	320-275	335-500
.500	Graves - % Elong.	370-135	360-150	240-300	180-140	168-425

Width	psi	I2 Butyl	P1 Thiokol
.250	Tensile - % Elongation	835-510	920-400
.400	Unnicked Crescent - % Elong.	465-310	380-300
.380	Nicked Crescent - % Elong.	200-175	189-140
.500	Graves - % Elongation	134-100	133-50
Based on Equivalent Thickness and Width			
.500	Tensile - % Elongation	665-350	535-365
.500	Unnicked Crescent - % Elong.	595-310	475-300
.500	Nicked Crescent - % Elong.	263-175	248-140
.500	Graves - % Elongation	134-100	133-50

TABLE XII

PERCENTAGE AVERAGE DEVIATIONS IN TEAR RESULTS OF HEVEA, GR-S, AND BUTYL FILLED WITH VARIOUS PARTICLE SIZED FILLERS

		NATURAL RUBBER-A8			GR-S - S7F1			BUTYL I7		
Filler	Method	Tear lb/in.	Ave. Dev. Lbs.	% Ave. Dev.	Tear Lb/in.	Ave. Dev. Lbs.	% Ave. Dev.	Tear lb/in.	Ave. Dev. Lbs.	% Ave. Dev.
CC	ASTM	904	54	6.0	358	72	20	265	15	5.7
CC	Graves	486	97	20.2	170	16	9.3	102	5	5.0
HiSil	ASTM	506	79	15.6	262	14	5.4	190	18	9.5
HiSil	Graves	232	72	31.0	134	15	11.0	76	4	5.5
HAF	ASTM	583	48	8.2	283	37	13.1	150	14	9.5
HAF	Graves	161	21	13.0	161	9.6	6.0	108	8	7.7
Acet.	ASTM	418	27	6.4	219	23	10.1	148	50	20.2
Acet.	Graves	170	30	17.7	162	5.3	3.3	93	5	5.5
SRF	ASTM	397	51	12.8	182	18	9.7	104	15.4	15.0
SRF	Graves	147	16	11.1	152	5.6	3.7	83	5.9	7.1
MT	ASTM	196	55	28.0	84	13.7	16.3	55	7.1	13.0
MT	Graves	133	11	8.3	70	5.2	7.5	56	11.3	20.2
Gum	ASTM	218	18	8.3	43	2.6	6.0	48	4.3	9.0
Gum	Graves	81	7.6	9.4	11	1.3	11.8	60	7.4	12.3
TOTALS	ASTM			12.2			11.5			11.7
	Graves			15.8			7.5			9.0

TABLE XIII
PERCENTAGE AVERAGE DEVIATIONS IN TENSILE RESULTS

Filler	NATURAL RUBBER-A8 Tensile psi	Ave. Dev.	% Ave. Dev.	GRS-S7F1 Tensile psi	Ave. Dev.	% Ave. Dev.	BUTYL I7 Tensile psi	Ave. Dev.	% Ave. Dev.
CC	4070	215	5.3	2600	115	4.7	2370	86	3.6
HiSil	2835	65	2.3	1000	67	6.7	2140	109	5.1
HAF	2920	170	5.8	2175	240	11.0	2100	168	8.0
ACET.	2200	164	7.4	1890	103	5.4	1760	259	14.7
SRF	1840	140	7.6	1710	66	3.9	1840	123	6.7
MT	1980	162	8.2	570	77	13.6	1560	240	15.5
GUM	1850	84	4.5	-	-	-	2220	215	9.7
TOTALS			5.9			7.5			9.0

Ten specimens were used in each case and the data analyzed as described in report.